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Changes of WBGT as a heat stress index over the time: A systematic review and meta-analysis

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ABSTRACT

The WBGT index is a common method to evaluate heat stress in the workplaces based on human physiological responses to environmental conditions. This systematic and meta-analysis study was aimed to estimate the mean value of the WBGT index in industries. The search protocol of this study was carried out according to PRISMA checklist. According to the heterogeneity of studies, a meta-analysis was done using a random effects model. The total value of WBGT index in the world according to this study was obtained 28.92 °C (95% CI: 28. 49–29. 35). The results regarding the fixed effect analysis showed that, average WBGT index before and after 2010, was estimated to be 26.63 °C (95% CI: 26.53–26.73) and 29.78 °C (95% CI: 29.71–29.85), respectively. The mean value of WBGT index in the men and women participants were 29.42 and 24.26 °C, respectively. The finding indicated that the average value of WBGT index is rising over time. The reason for this may be attributed to global warming or lack of proper physical work condition in these environments. It would be alarming for the workers who worked in outdoor environments or hot operating conditions.

1. Introduction

Hot-dry and hot-humid environmental conditions are common in many parts of the world; these conditions can lead to problems for exposed workers and it is an undeniable reality in developing countries (Akbari et al., 2013; Aliabadi et al., 2012). Ecological studies have shown that extreme heat can increase mortality in the society (Alimohamadi et al., 2012). Recently, various heat-related studies have been conducted on vulnerable populations such as children, the elderly and patients with chronic diseases (Angle and Gillette, 2011); the increased risk of heat-related illnesses and injuries to workers has been investigated at the various indoor and outdoor environments, as well (Ansari et al., 2014). Rising concern about the environmental impact of climate change on public health was introduced in the late 1990s (Azari et al., 2011). Increasing ambient temperature is one of the consequences of climate change. It is especially important because a large number of workers are working in outdoor environments and directly expose to heat. Exposure to heat stress can cause a variety of heat related problems such as heat syncope, heat exhaustion, heat cramps, heat shock, confusion, poor concentration, fatigue, and also impose some costs such as loss of production, loss of workers' income and increase social expenses ((Moran and Epstein, 2006)11). According to the above-mentioned descriptions, heat stress is considered a serious hazard which can cause health problems for workers in some industries. In order to evaluate heat stress in workplace,

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Table 1
Description of cross-sectional studies.

Industry	locations	N	Year Publication	Researcher
–-	Israel	409	2001	Moran
Runner	USA	17	2002	Clements
Bakery	Iran	175	2005	Hanani
Steel	Iran	90	2005	Clantary
Football	–-	139	2006	Cooper
Baker	Iran	88	2006	Golmohamadi
–-	Japan	6	2007	shinji yamamoto
Glass manufacturing	Iran	40	2008	Pourmahabadian
Construction	United Arab Emirates	66	2008	Graham P Bates
Football	USA	25	2010	Yeargin
Pottery, agricultural, construction, power plant, knife industry	Thailand	21	2010	Langkulsen
–-	Malaysia	10	2010	Ismail
–-	USA	25	2011	Angle
Furnace worker	Iran	36	2011	Azari
Smelters	Iran	27	2011	Haji Azimi
Bakery	Iran	126	2012	Aliabadi
Petrochemical and steel	Iran	122	2012	Dehghan
Oil Terminals	Iran	94	2012	Alimohamadi
south pars	Iran	71	2012	Dehghan
Harvesters	USA	105	2013	Crowe
Small workshops	Iran	25	2013	Hajizadeh
Car assembly	Iran	173	2013	Akbari
Petrochemical Complex	Iran	20	2013	Hemmatjo
Cookie factory, Canteen, Laundry, Agriculture, Construction	Europe	46	2014	Lundgren
Brick Workshops	Iran	184	2014	Hajizeh
Athletic	Iran	32	2014	Golbabaei
Auto parts manufacturer	Iran	30	2014	Golbabaei
Sugar beet workers	Iran	20	2014	Golbabaei
Chamber	Iran	30	2015	Habibi

Table 2
Description of case-control studies.

Industry	locations	N		Year Publication	Researcher
		Control	Case		
Smelting	Iran	28	120	1992	Nassiri
Oil Terminals	Iran	94	94	2012	Alimohamadi
Hot workplaces	Iran	20	40	2013	Jalali
Metal melding industry	Iran	35	35	2014	Ansari
Petrochemical Company	Iran	11	10	2013	Golbabaei
Petrochemical	Iran	11	10	2013	Monazzam
Malibel Saipa Company	Iran	35	35	2014	Mazloumi
Construction Workers	Iran	30	30	2014	Farshad
Auto parts manufacturer	Iran	10	20	2014	Golbabaei

environmental measurement, determination of heat exchange rate between the worker and the environment and also monitoring of some human physiological parameters are recommended. In this regard, two international standards such as ISO 7933 and 9886 have been developed for evaluating heat stress. There are large number of heat stress indices for assessing heat stress in the workplaces. Some of the most popular indexes are WBGT, Sweat rate required (SW req), Discomfort Index (DI), P4SR, ET, CET, HIS and etc. Over a century, attempts have been made to construct an index, the heat stress indexes which has had better correlation with physiological parameters (Epstein and Moran, 2006). Among various researches which have been conducted to investigate the performance of different heat stress indexes for estimation of thermal stress, Wet Bulb Globe Temperature (WBGT) index found to be a suitable index to assess the climatic condition of the working environments (Falahati et al., 2012). This index has the ability to assess the effects of heat exposure in a period of time for a specific activity and it is one of the easiest and most appropriate heat assessments indexes. WBGT index is the only index which is widely accepted by the researchers (Golbabae et al., 2014; Golbabaei et al., 2013). This index was introduced by the International Organization for Standardization (ISO) for the assessment of heat stress (Golbabaei et al., 2014). The most important strength point of the WBGT index is the sensitivity to radiant heat and air flow, which are two essential elements in determining the ambient air temperature. Despite the advantages mentioned, this indicator has some limitations, including: the relatively long time needed for temperature stabilization of the temperature sensors for globe and wet temperatures, low precision of this index at low air flow rates or high humidity, and also the need to estimate metabolism rate and Insulating resistance of clothing.

Global warming due to increased greenhouse gases, especially in the warm seasons, has exposed many people to heat stress. By

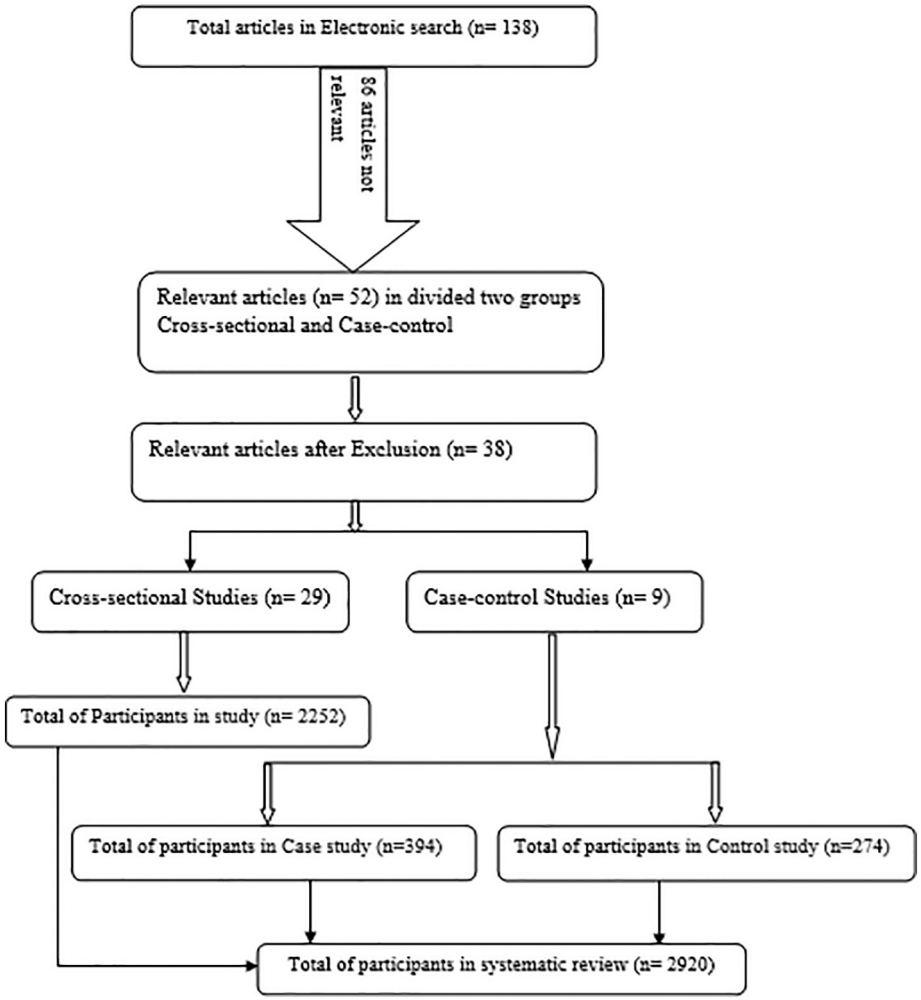
Total articles in Electronic search (n= 138)
86 articles not relevant
Relevant articles (n= 52) in divided two groups Cross-sectional and Case-control
Relevant articles after Exclusion (n= 38)
Cross-sectional Studies (n= 29)
Case-control Studies (n= 9)
Total of Participants in study (n= 2252)
Total of participants in Case study (n=394)
Total of participants in Control study (n=274)
Total of participants in systematic review (n= 2920)

Diagram 1. PRISMA flowchart of the study selection process.

applying WBGT index, we will be able to assess working heat stress and take technical and engineering control measures to protect the exposed population to heat stress.

The continuing climate change has led to temporal and spatial alterations of workplace heat exposure into occupational health issues in tropical and subtropical parts of the world. In this regard, the results of the previous studies indicate that the WBGT values is increasing over the past few years.

Giving the aforementioned description, the trending WBGT index as an accepted indicator for monitoring climate change especially in warm seasons is great of importance. To the best of our knowledge and searching in the literature, there was not any systematic and meta-analysis study to investigate the mean value of the WBGT index and its change over time. Therefore the main purpose of this study was to investigate the mean value of WBGT index and trending its changes over time.

2. Materials and methods

2.1. Research strategy

This systematic review and meta-analysis study was conducted in April 2016. In order to find related published articles on WBGT index, the electronic databases such as Elsevier, Google, Google scholar, Scientific Information Databases (SID) and Scopus were examined. The search protocol was designed using mainly advised methods as well as PRISMA protocol (Habibi et al., 2015). Search strategy involves a combination of several keywords related to the field of research including heat stress and WBGT, WBGT index, environmental stress and occupational exposure indexes.

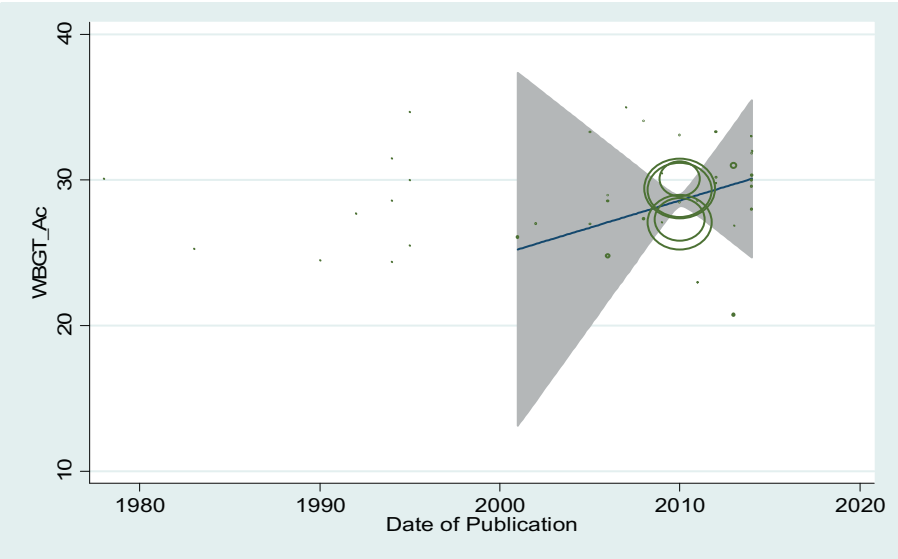

Fig. 1. Meta-regression diagram of the mean value of WBGT and its mean is increasing with the year, the larger diameter of the circle the higher mean of WBGT.

2.2. Study selection and data extraction

All potentially relevant studies were independently assessed and screened for eligibility by two researchers. Almost all WBGT related found studies were considered. Average of WBGT value and geographic region of the study were the primary and secondary outcome of the assessed studies, respectively. Furthermore, the searched articles according to the study type were divided into two categories: cross-sectional and case-control studies. Extraction of data from reviewed studies was performed by two researchers independently according to a standard pattern. The data included the author's name, title, year and location of the study, sample size, and sex were extracted and recorded. A total of 138 articles were found that finally 38 articles were selected for the study, of which, 29 articles were cross-sectional and 9 articles were the case-control study. This study was the first systematic review and meta-analysis in this field in Iran.

2.3. Statistical analysis

The effect size (ES) in this study was defined as WBGT mean value. WBGT mean value and its standard deviation (SD) were extracted in all reviewed studies. In some of the studies the SD was not reported directly, it was estimated using confidence interval (CI) or standard error. According to the heterogeneity of studies, to pooled effects size across studies, the random effects model or fixed effects model was used. Heterogeneity of studies was checked using Q test and I^2 statistics. Subgroup analysis was also done based on to continent type. Association between WBGT mean value and the study year were checked using meta-regression. All required analysis was carried out using STATA Ver. 10.

3. Results

During the searching process within different databases, a total of 138 articles were obtained from the literature search. After removal of duplicated and unrelated studies, 38 articles were selected for analysis. The assessed articles were divided into two groups of cross-sectional and case-control studies. The description of studies that met our criteria is presented in Tables 1 and 2.

The numbers of participating in the cross-sectional and case-control studies were 2252 and 668, respectively. Of 668 case-control participants, 394 subjects were in cases group and 274 subjects were in the control group (Diagram 1).

As Fig. 1 shows, the majorities of the cross-sectional studies have been conducted date to 2010. Furthermore, most studies were conducted between 2008 and 2014. However, the average of WBGT index showed a growing trend in different years; this increase was not statistically significant (0.417).

The average of WBGT index in 29 cross-sectional articles was reviewed. Fig. 2 presents the average of this index in Asia, Europe, and America continents. Based on our analysis, the average of WBGT index was 29.9 °C (95% CI: 28.6–29.58), 29.5 °C (95% CI: 28.46–30.54), and 26.81 °C (95% CI: 25.32–28.31) in Asia, Europe, and America continents, respectively. The total mean value for WBGT index in the all reviewed article in cross-sectional studies was 28.92 °C (95% CI: 28. 49–29. 35).

In Iran, the pooled estimation of the mean value for WBGT index using random effects modes was 29.7 °C (95% CI: 27. 84–31. 59).

Investigation of the cross-sectional studies revealed that four researches had been done on the female's gender. The mean values of

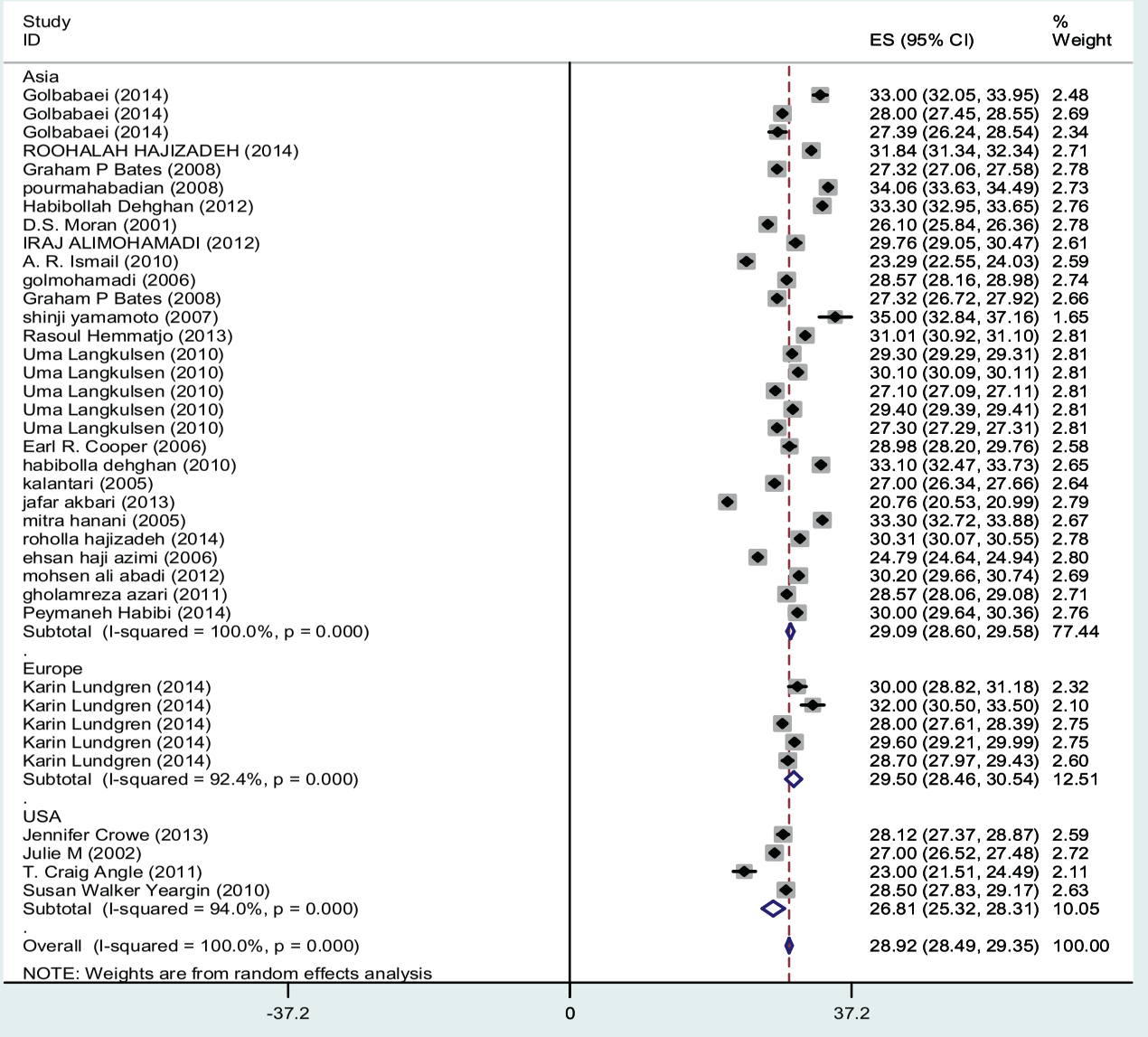

Fig. 2. The mean of WBGT different continents. Squares represent the effect estimate of studies with 95% confidence intervals with the size of squares proportional to the weight assigned to the study in the meta-analysis. The diamond shows the overall results and 95% confidence interval of the random effect of meta-analysis.

WBGT index in the females and males participants were 24.26 °C (95% CI: 18.64–29.88) and 29.42 °C (95% CI: 28.2–30.64), respectively.

Based on confidence interval 95% and the effect size in fixed effect analysis and mixed effect analysis groups, the WBGT index in both groups before and after 2010 was also investigated. Considering the fixed effect analysis, the results indicated that the average values for WBGT index before and after 2010, were 26.63 °C (95% CI: 26.53–26.73) and 29.78 °C (95% CI: 29.71–29.85), respectively. Moreover, the mean values for WBGT using mixed effect analysis before and after 2010, were found to be 28.44 °C (95% CI: 26.64–30.23) and 28.83 °C (95% CI: 26.98–30.69), respectively.

The second part of this study was aimed at the analysis of the case-control studies which almost all have been carried out in Iran. In these studies, case groups were workers working in operational units (casting, smelting, foundry platform, and outdoor) and were exposed to heat stress during their activities. The control group was also worked in the same workplace (unit reception, warehousing, control room, restroom, and indoor), but had no exposure to thermal stress.

As can be seen in Fig. 3, the average value of WBGT index in all studies was significantly higher than case group. Minimum and maximum observed differences between the averages values of WBGT were attributed to Golbabaei (2014) and Ansari (2014) works with 0.77 °C and 4.92 °C, respectively. Generally, the average value for WBGT index in the case group was 2.83 °C (95% CI: 1.80–3.85) higher than the control group. Statistical analysis showed a significant correlation ($P < .05$).

Fig. 3 shows the weight percent factor (%) for each study and its impact on the total weight. In this study, the weight percent of the reviewed papers was almost close together which represents the homogeneous case and control groups as well as the high accuracy of the reviewed studies.

In this study, the publication bias test and sensitivity analysis were used to exam the accuracy of the meta-analysis.

Although the results of some studies were not statistically significant, the results of these studies have been reported and this gives a high degree of credibility to the present study (Fig.4). In this study, the effect of Publication bias test was not significant ($P = .142$) indicating that the results are reliable.

Fig. 5 shows the sensitivity analysis of the study. This test shows the effect of each study separately on the overall result. As it can be seen from Fig. 5, removing any study would not affect the total results which suggest that the results are a reliable estimation of both cases and controls groups.

4. Discussion

4.1. Main findings

Considering the reviewed studies, the average value for WBGT index was estimated to be 28.92 °C (95% CI: 28. 49–29. 35) in the world. The lowest and highest average values for WBGT index were obtained for American (23 °C) and Asia (35 °C) continents, respectively. It is worth to mention that the average value of WBGT index was estimated to be 29.7 °C (95% CI: 27. 84–31. 59), in Iran. Moreover, heterogeneity test findings showed that the results were different on each continent ($P = .000$, $I2 > 92.4\%$), so that the highest heterogeneity was in Asia, America, and Europe, respectively.

4.2. Interpretations

Although the average value obtained of WBGT for Iran and world is almost close to each other, reasons for the small difference could be referred to atmospheric phenomena and climatic conditions.

Based on the results of the present study, WBGT average values for studies which conducted on women as participants were found to be 5.16 °C less than those studies carried out on men. The reasons for the observed difference may be due to the working conditions, outdoor environments heat and also performing certain jobs such as heavy jobs and outdoor activities by men.

Statistical analysis results revealed that the average value for WBGT index after 2010 compared to previous years was higher. The results of the fixed effect analysis test and mixed effect analysis test confirmed that the average value of WBGT was higher after 2010 in comparison to previous years. The reason could be due to the increase in global temperature and warming. Finding of Marois et al., study is consistent with the results of our study (Cooper et al., 2006).

In all reviewed case-control studies, the average value of WBGT in case groups was higher than the control groups. This study finding indicated that the observed temperature differences for case and control groups were 2.83 °C. The reasons could be due to the existing operating conditions and also heat exposure during activities for the case group.

5. Limitations

The present systematic review and meta-analysis study has some limitations. Since most of conducted studies in this field are related to areas having hot climate and outside activities, the distribution of the WBGT related studies in the various continent is different. It is more important when we want to compare the results around the world. The lack of related articles and data provided in the articles were the other constraints of this study.

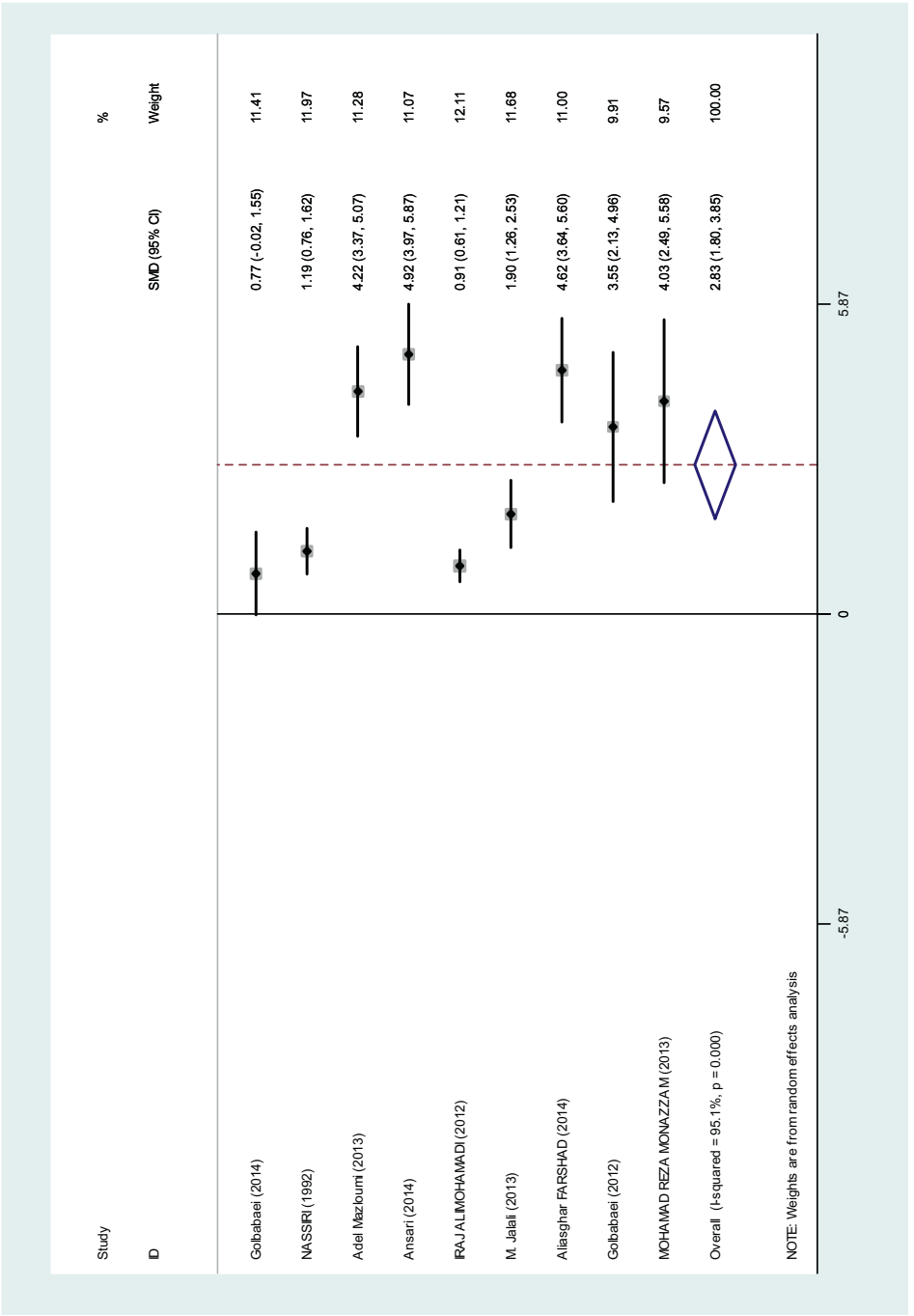

Fig. 3. The standardized difference between the mean values of WBGT index in case and control groups.

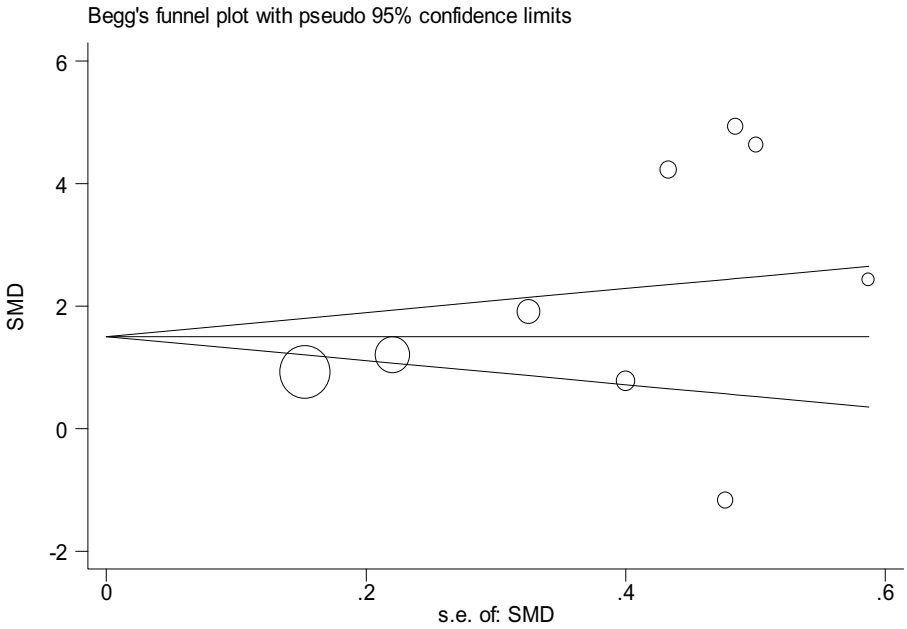

Fig. 4. Publication bias.

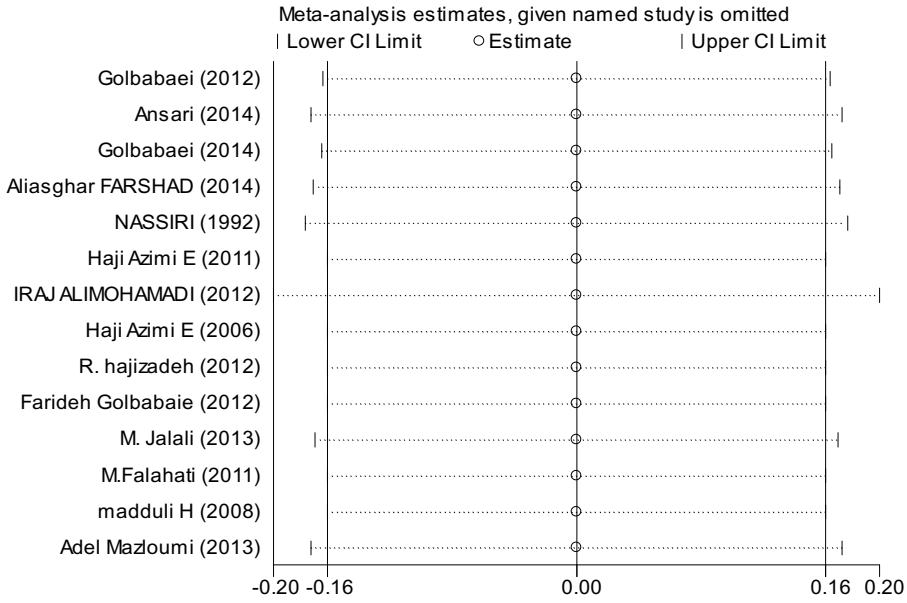

Fig. 5. Sensitivity analysis.

6. Conclusion

The results showed that the average value for WBGT index is rising. The reason for this increase may be due to global warming or lack of proper physical work conditions in these environments. It would be alarming for workers working in outdoor environments or hot operating conditions. Therefore, regarding the harmful effects of the heat on workers' health and impose additional expenses on the workers and industry, it is necessary to consider working conditions of this group.

Competing interest

The authors have no competing interests to declare.

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